Microscopy of Antiferromagnetic Surfaces

First Surface Image with Clear Antiferromagnetic Contrast

Researchers from the IBM Almaden Research Center, the Advanced Light Source (ALS), Stanford University, and Arizona State University have used the new PEEM2 photoemission electron microscope at the ALS to record the first unambiguous images by any technique showing antiferromagnetic contrast on a thin film surface. Since antiferromagnetic films are key components in the multilayer devices in use for read heads in magnetic-disk data-storage systems and under development for non-volatile memory in future generations of computer random-access memory, the new imaging tool demonstrated on nickel oxide could have a significant commercial impact, as well as contribute to a fundamental knowledge of magnetic materials.

In antiferromagnets, the magnetic moments of neighboring atoms are aligned along an axis, but there are as many moments in one direction as the other, so that the net moment is zero. Techniques like x-ray magnetic circular dichroism that are well-established for investigating the magnetic structure of ferromagnetic thin films and surfaces do not work with antiferromagnets, owing to the lack of a net magnetic moment for the circularly polarized x rays to interact with.

X-ray magnetic linear dichroism (XMLD) provides a way around the dilemma. Absorption of linearly polarized light depends on the square of the magnetic moment (so the opposite moments do not cancel) and has an angular dependence, varying with the cosine squared of the angle between the antiferromagnetic axis and the polarization. Researchers elsewhere have tapped these qualities of XMLD to probe antiferromagnetic nickel oxide films. What the group working at the ALS added was the use of the PEEM2, which images with a spatial resolution of about 50 nm the electrons emitted from the surface of a thin film as the result of x-ray absorption. The image intensity measures the amount of absorption at each point on the surface.

At the ALS, the researchers studied films of nickel oxide with thicknesses from 10 to 80 nm deposited on a magnesium oxide substrate. They made images with PEEM2 at the L_2 edge of nickel, which splits into two peaks (multiplet splitting) with heights that depend in opposite ways on the angle between the x-ray polarization and the antiferromagnetic axis. Dividing the intensities at each point of an image made at one of the multiplet peaks by those in the image made at the other gives an image dominated by antiferromagnetic contrast. The image of nickel oxide obtained in this way showed bright lines with typical widths from 400 to 2000 nm, indicating that the average antiferromagnetic moment was different in the stripes and in the dark background. The striped structures were correlated with surface defects observed with atomic force microscopy. With a resolution of 50 nm, however, the PEEM2 could not resolve individual antiferromagnetic domains, which the atomic force microscopy images suggested were smaller than this.

To further confirm that the image contrast was due to the antiferromagnetic structure of the sample, the researchers made measurements as the temperature of the samples approached the Néel temperature of nickel oxide above which antiferromagnetism disappears. In a series of images acquired at increasing temperature, the visually observable contrast between the stripes and the defect-free dark areas disappeared. The researchers found that the ratio of the multiplet peak heights, which is sensitive to the magnetic state of the surface, in the dark areas approached the expected non-antiferromagnetic value at the Néel temperature, whereas the image contrast between stripes and background reached a constant value about 65 K below the Néel temperature. The researchers interpreted the lower effective Néel temperature in the stripes as a reduced ordering temperature due to the small size of the stripes (finite size effect). ■

Joachim Stöhr (408-927-2461) IBM Almaden Research Center, San Jose, CA 95120 and Simone Anders (510-486-5928), Advanced Light Source, E.O. Lawrence Berkeley National Laboratory.

Stöhr, J., A. Scholl, T.J. Regan, S. Anders, J. Lüning, M.R. Scheinfein, H.A. Padmore, and R.L. White, "Images of the Antiferromagnetic Structure of a NiO(100) Surface by Means of X-Ray Magnetic Linear Dichroism Spectromicroscopy," *Phys. Rev. Lett.* **83** (1999) 1862.

RESEARCH FUNDING: Division of Materials Sciences (DMS), U. S. Department of Energy; Stanford University Center for Materials Research; and International Disk Drive Equipment and Materials Association. Operation of the ALS is supported by DMS.

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- **Antiferromagnetic films are key players in magnetics industry**
  - *State-of-the-art read heads for data-storage disks*
  - *Future non-volatile, random-access memories for computers*
- **Spatially resolved spectroscopy of antiferromagnets**
  - *Dissect magnetic behavior of films and interfaces with other layers*
  - *Sensitive to orientation of the antiferromagnetic axis with high spatial resolution*
- **X-ray magnetic linear dichroism spectroscopy**
  - *Dichroism due to fine structure (multiplet) at absorption edge*
  - *Absorption depends on polarization relative to the antiferromagnetic axis*
- **First spectromicroscopy results with nickel oxide films**
  - *Absorption of x rays results in emission of electrons from the surface*
  - *PEEM2 photoemission electron microscope at the ALS images absorption*
  - *Unambiguous antiferromagnetic contrast obtained at 50-nm spatial resolution*

J. Stöhr and J. Lüning (IBM Almaden Research Center); A. Scholl, S. Anders, and H. A. Padmore (ALS); T. J. Regan, and R. L. White (Stanford University); and M. R. Scheinfein (Arizona State University). [*Phys. Rev. Lett.* 83 (1999) 1862]

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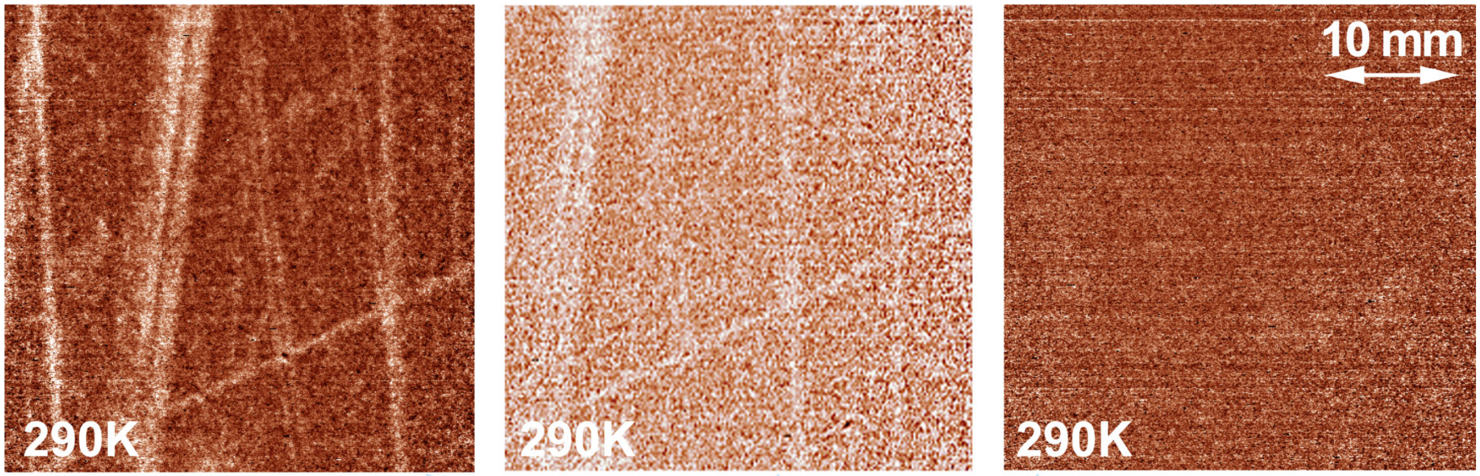
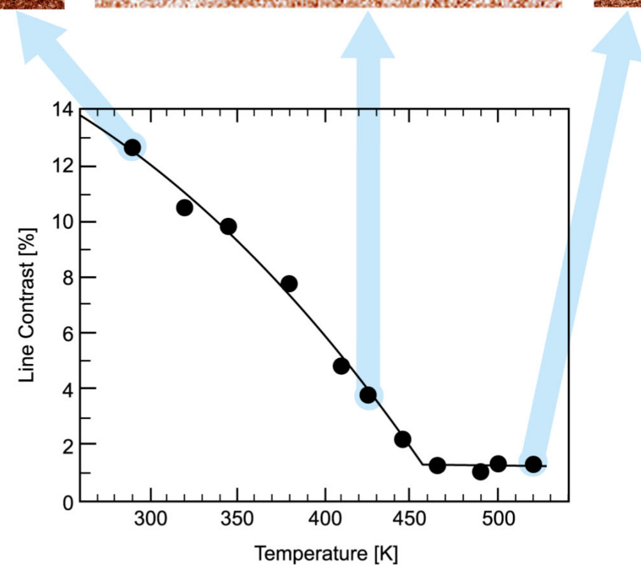
First Surface Image with Clear Antiferromagnetic Contrast



XMLD antiferromagnetic image of a NiO film shows stripes associated with defects against a defect-free dark background.



The disappearance of contrast as the temperature approaches the Néel temperature of NiO confirms that the contrast is antiferromagnetic.

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